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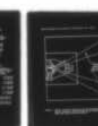
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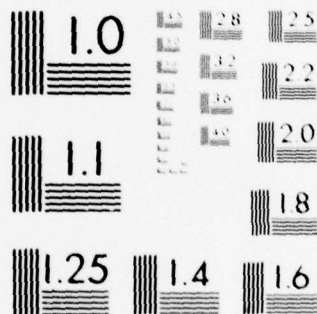
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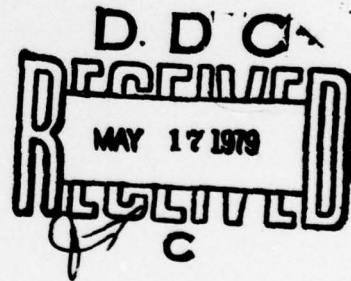
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**UNITED STATES ARMY  
ENVIRONMENTAL HYGIENE  
AGENCY**

**ABERDEEN PROVING GROUND, MD 21010**

NONIONIZING RADIATION PROTECTION SPECIAL  
STUDY NO. 25-42-0310-79  
HAZARD EVALUATION OF THE COHERENT MODEL 900  
PHOTOCOAGULATOR LASER SYSTEM  
JANUARY - FEBRUARY 1979



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15 MAY 1979

HSE-RL/WP

SUBJECT: Nonionizing Radiation Protection Special Study No. 25-42-0310-79,  
Hazard Evaluation of the Coherent Model 900 Photocoagulator Laser  
System, January - February 1979

Commander  
US Army Health Services Command  
ATTN: HSPA-P  
Fort Sam Houston, TX 78234

A summary of the pertinent findings and recommendations of the inclosed report follows:

a. A special study of the Coherent Model 900 photocoagulator was performed by this Agency. It was determined that the laser emits optical radiation exceeding current protection standards. It was also determined that although the alignment beam, when reflected back through the slit-lamp optics, exceeds prolonged viewing standards at the higher alignment beam powers, the alignment beam will not present a significant hazard at normal settings for surgical procedures.

b. It was recommended that the alignment beam be used on as low a power setting as possible, that intrabeam viewing by unprotected personnel not be allowed within 7 m for direct viewing or 1.6 m when viewing the coated gonial lens reflection, that an adequate SOP be posted that clearly states the hazards of this device, that unprotected personnel not be allowed in the vicinity where the laser is operating due to possible hazardous laser reflections from the gonial lens, and that only gonial lenses with anti-reflective coatings be used.

FOR THE COMMANDER:

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ABERDEEN PROVING GROUND, MARYLAND 21010

NONIONIZING RADIATION PROTECTION SPECIAL  
STUDY NO. 25-42-0310-79  
HAZARD EVALUATION OF THE COHERENT MODEL 900  
PHOTOCOAGULATOR LASER SYSTEM  
JANUARY - FEBRUARY 1979

1. **AUTHORITY.** Letter, ATZC-MDHE, William Beaumont Army Medical Center, 5 October 1978, subject: Laser Protection Survey by US Army Environmental Health Agency, and indorsement thereto.

2. **REFERENCES.** See Appendix A for listing of references.

3. **PURPOSE.** To evaluate the potential health hazards associated with the use of the Coherent Model 900 photocoagulator and to make recommendations designed to eliminate exposure of personnel to potentially hazardous optical radiation from this device.

4. **GENERAL.**

a. **Background.** Due to the laser energy levels required for the surgical procedure, i.e., retinal repair by photocoagulation, coupled with the optics required for observation of the fundus of the eye, the potential optical hazard to either the ophthalmologist performing the surgery or to an observer from laser use is fairly large. Since use of the laser photocoagulator in general, and the Coherent Model 900 unit in particular, is becoming common throughout the Army Medical Department, an optical hazard special study of this device was of broader interest. During the month of January 1979, representatives of this Agency, with the assistance of staff members at the respective facilities, performed measurements on the Coherent Model 900 photocoagulators located at Ophthalmology Services, William Beaumont Army Medical Center, Letterman Army Medical Center, and at Walter Reed Army Medical Center.

b. **Description.** The Model 900 photocoagulator uses one argon ion laser for both alignment of the beam for treatment on the particular portion of the retina desired, and for the actual photocoagulation. The laser beam is presented coaxially to a slit-lamp optical system by a fiber optic bundle (Figure 1). Neutral density filters attenuate the beam when in the alignment mode. The neutral density filters also act as a shutter, as depression of a foot pedal removes the attenuation for a preselected time interval. Consequently, an increase in the power required for photocoagulation produces

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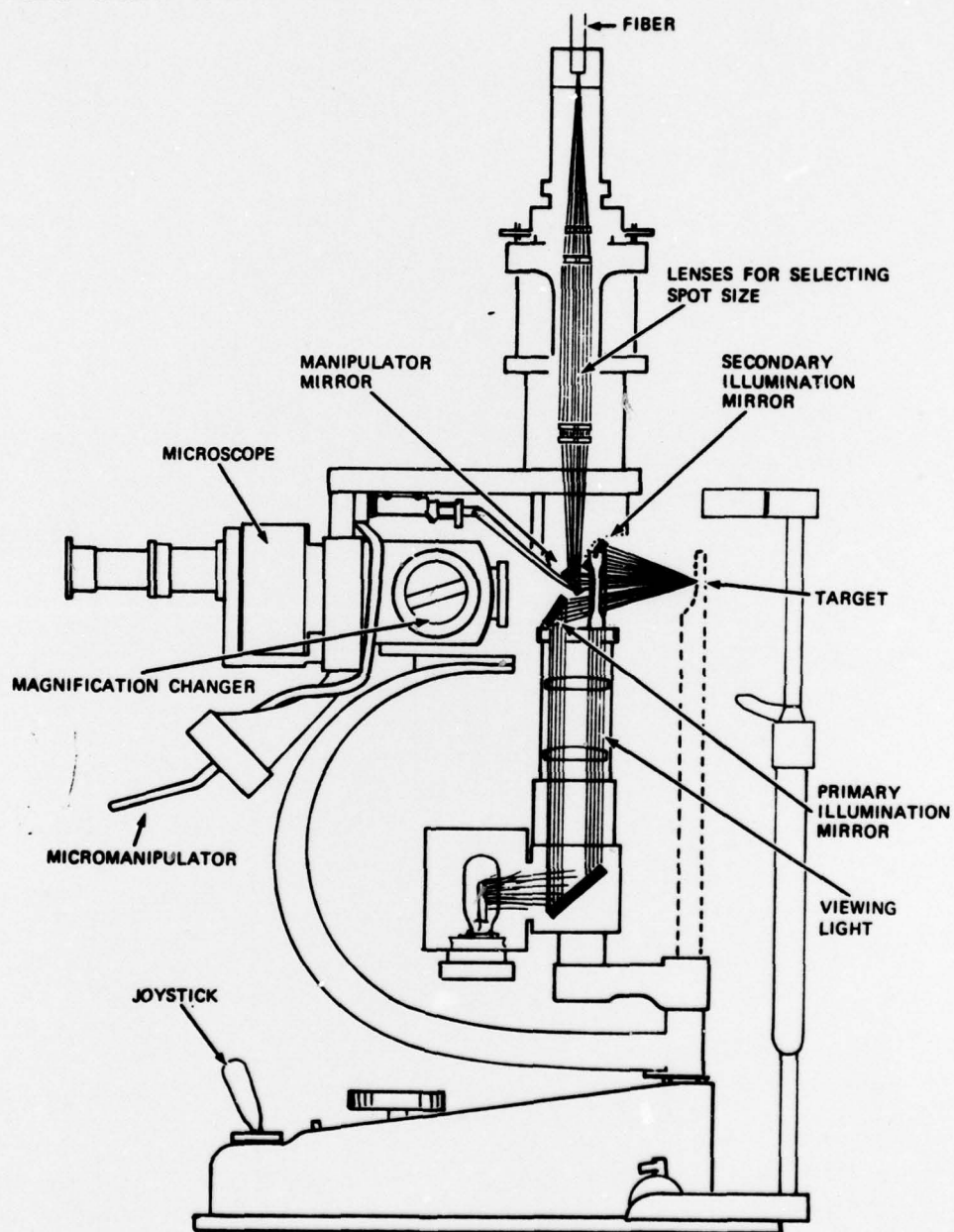


FIGURE 1. ZEISS SLIT-LAMP OPTICAL GUIDE. Laser light is delivered by the fiber at the top of the figure.

a corresponding increase in the alignment beam power. Prior to the removal of the attenuation for the main beam, a blocking filter is inserted into the slit-lamp optics. This filter attenuates the laser energy that is reflected off the gonial lens back through the optics. No attenuation of the reflection of the alignment beam is provided. A coating on the gonial lens does reduce the alignment beam power from the level that would be reflected if no coating were present. Figure 2 demonstrates a typical patient positioned in front of the slit-lamp/photocoagulator optics.

c. Instrumentation. A list of the instrumentation used in this study is provided below:

- (1) EG&G Model 580 Radiometer System with Model 22A detector head.
- (2) Calibrated circular apertures.
- (3) Calibrated neutral density filters.

d. Abbreviations. A table of radiometric terms and units is provided in Appendix B.

## 5. FINDINGS.

a. Laser Output Parameters. Radiometric measurements were performed on the Coherent Model 900 photocoagulators at William Beaumont Army Medical Center during 8-12 January 1979, at Walter Reed Army Medical Center on 29 January 1979, and at the Letterman Army Medical Center during 14-15 February 1979. The following laser output parameters were determined:

Wavelength: limited to 488.0 nm and 514.5 nm.

Pulse duration:

alignment: cw

photocoagulator: adjustable for 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5 seconds, or a cw mode. The most common pulse duration used for photocoagulation was 0.2 second.

Radiant Energy: The photocoagulator is continuously adjustable up to 2 watts delivered to the cornea. The most common bracket for the power setting was from 200-500 mW, with a maximum indicated radiant power of 700 mW for special surgical applications. The alignment beam also could be adjusted with 4 stops that would deliver: #1, 0.008 mW; #2, 0.08 mW; #3, 0.8 mW; and #4, 8 mW with a photocoagulator setting of 1 W. These values would change proportionally with a change in the photocoagulator power level. Table 1 provides values of radiant power for two common brackets of photocoagulator power settings for both the alignment and photocoagulator beams.



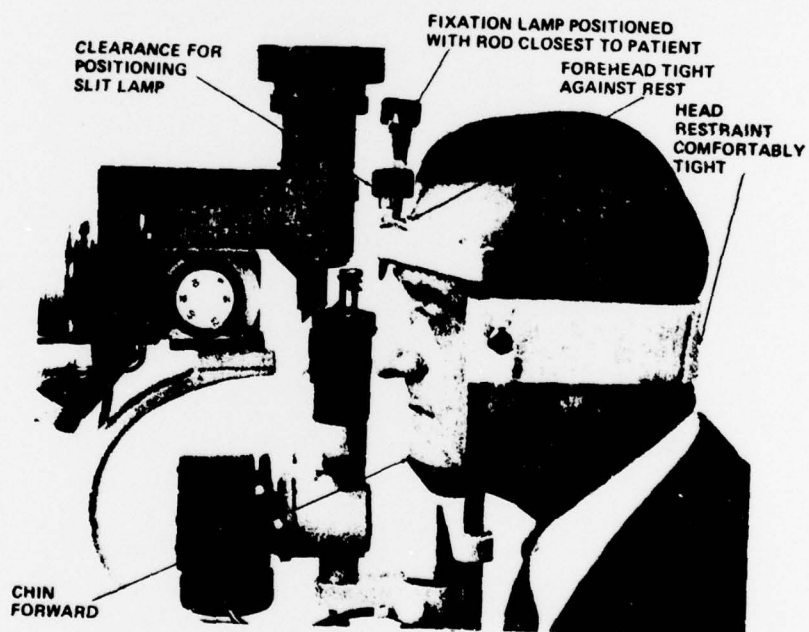


FIGURE 2. Patient positioned in front of the slit-lamp optics.

Effective beam divergence: 23.8 mrad at 1/e-peak-radiant-exposure points. The beam is focused at a point from the exit mirror that varies as a function of the retinal spot size desired.

Retinal spot size: continuously adjustable from 50-2000  $\mu\text{m}$ .

Effective beam diameter: 1 mm at the focus of the beam outside of the eye.

Blocking filter attenuation: (values specified by filter manufacturer)  
488.0 nm = 150 dB (15 O.D.)  
514.5 nm = 110 dB (11 O.D.)

Irradiance: See Table 1 for irradiance values with no patient positioned in the beam and Table 2 for reflected irradiance through slit-lamp optics.

b. Labels. At the time of this study, there were adequate warning labels present on the three lasers measured which read: "DANGER. Visible Laser Radiation. Avoid Eye or Skin exposure to direct or scattered radiation. Argon Ion Laser. 9 Watts max. cw."

## 6. DISCUSSION.

a. Hazard Analysis. The most conservative protection standard for a pulsed argon laser (400-550 nm region) is given by:  $1.8 t/t^{1/4} \text{ mJ/cm}^2$ , where  $t$  is the pulse duration. For a laser with a pulse duration of 0.2 second, the protection standard is  $0.54 \text{ mJ/cm}^2$ . As would be expected, the photocoagulator beam exceeds the protection standard for all the common laser settings, with the Nominal Ocular Hazard Distance (NOHD) varying as a function of the laser setting used. The direct-beam NOHD for the 200-mW laser setting is 2.0 m, while the 500-mW setting has a NOHD of 7.4 m if the beam were not directed into the patient's eye. The anti-reflective coating on the gonial contact lens reflects 0.4 percent of the energy, consequently the specular reflection from the gonial contact lens is below the protection standard for laser settings below 500 mW. At settings of 500 mW or greater, the reflection off the gonial lens is above the protection standard. This presents no particular problem to the ophthalmologist viewing through the slit-lamp optics, as the blocking filter adequately attenuates the energy reflected off the gonial contact lens back through the slit-lamp optics. This does present a hazard to unprotected personnel viewing the photocoagulation process when they are located behind the ophthalmologist, as a specular reflection hazard does exist in this area (Figure 3). The alignment beam is below the momentary (0.25-s) protection standard ( $2.5 \text{ mW/cm}^2$  for all

TABLE 1. RADIOMETRIC MEASUREMENTS ON THE COHERENT MODEL 900 PHOTOCOAGULATOR. The radiant power settings measured are for the most common utilization of the instrument.

Mode	Photocoagulator Setting	Measured Radiant Output	Irradiance or Radiant Exposure (through 7 mm aperture)
Alignment #2	200 mW	0.015 mW	0.047 mW/cm <sup>2</sup>
	500 mW	0.038 mW	0.18 mW/cm <sup>2</sup>
Alignment #4	200 mW	1.54 mW	1.84 mW/cm <sup>2</sup>
	500 mW	3.85 mW	4.67 mW/cm <sup>2</sup>
Photocoagulation (0.25)	200 mW	43.0 mJ	53.8 mJ/cm <sup>2</sup>
	500 mW	107.0 mJ	134.5 mJ/cm <sup>2</sup>

TABLE 2. RADIOMETRIC MEASUREMENTS ON THE LASER ENERGY REFLECTED BACK THROUGH THE SLIT-LAMP OPTICS.

Reflector	Mode	Photocoagulator Setting	Measured Radiant Output	Irradiance or Radiant Exposure (through 7 mm aperture)
Non-coated lens	alignment #2	200 mW	0.71 $\mu$ W	2.23 $\mu$ W/cm <sup>2</sup>
	alignment #2	500 mW	1.81 $\mu$ W	8.55 $\mu$ W/cm <sup>2</sup>
Coated lens	alignment #2	200 mW	0.057 $\mu$ W	0.179 $\mu$ W/cm <sup>2</sup>
	alignment #2	500 mW	0.144 $\mu$ W	0.68 $\mu$ W/cm <sup>2</sup>
Non-coated lens	alignment #4	200 mW	73.0 $\mu$ W	87.4 $\mu$ W/cm <sup>2</sup>
	alignment #4	500 mW	182.9 $\mu$ W	221.8 $\mu$ W/cm <sup>2</sup>
Coated lens	alignment #4	200 mW	5.85 $\mu$ W	6.99 $\mu$ W/cm <sup>2</sup>
	alignment #4	500 mW	14.6 $\mu$ W	17.7 $\mu$ W/cm <sup>2</sup>
Non-coated lens	photocoagulator	200 mW	2.04x10 <sup>-15</sup> mJ	2.56x10 <sup>-15</sup> mJ/cm <sup>2</sup>
	photocoagulator	500 mW	5.08x10 <sup>-15</sup> mJ	6.39x10 <sup>-15</sup> mJ/cm <sup>2</sup>
Coated lens	photocoagulator	200 mW	0.16x10 <sup>-15</sup> mJ	0.20x10 <sup>-15</sup> mJ/cm <sup>2</sup>
	photocoagulator	500 mW	0.41x10 <sup>-15</sup> mJ	0.51x10 <sup>-15</sup> mJ/cm <sup>2</sup>

\* These values calculated as measurement were beyond range of available instruments.



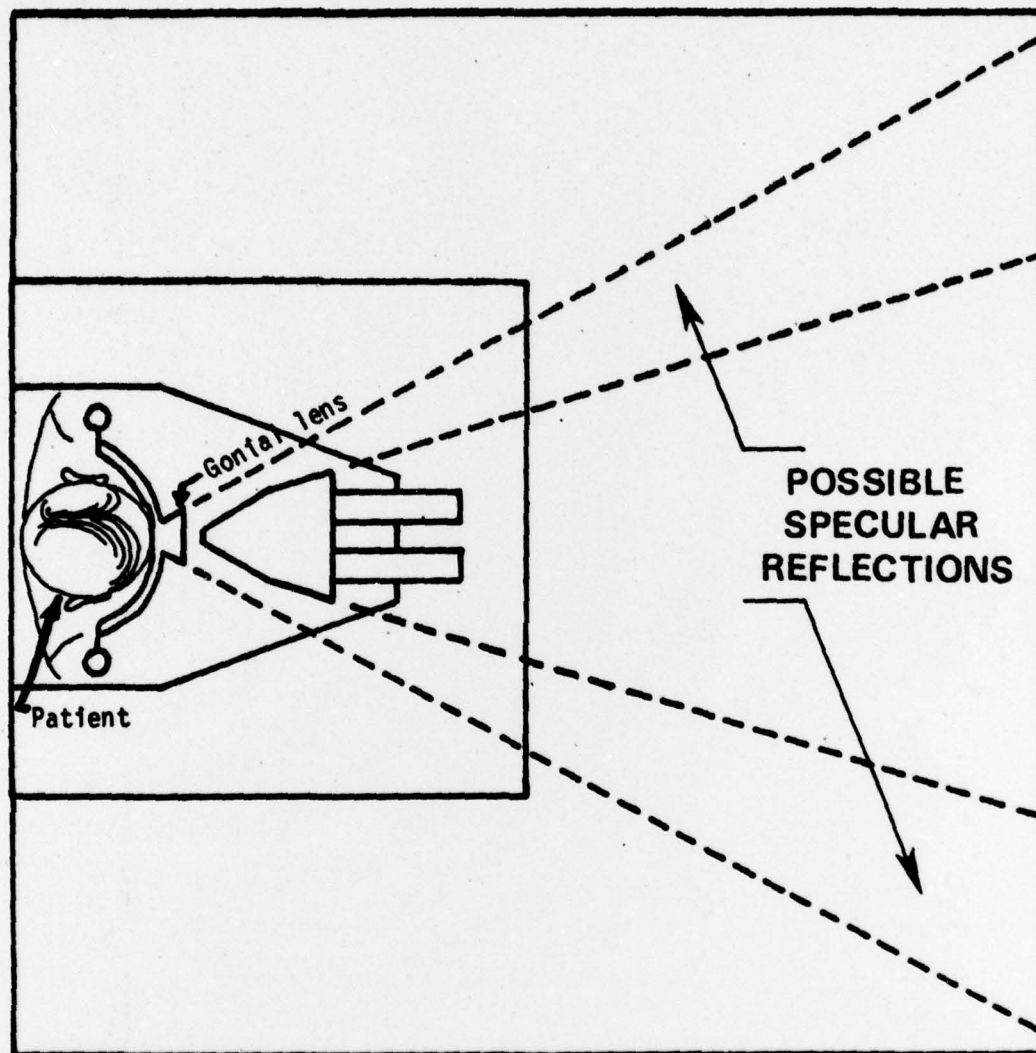


FIGURE 3. Specular reflection hazard area for the photocoagulator during a surgical procedure. Personnel observing the procedure while in these areas should have eye protection.



alignment settings except No. 4. For this setting, the alignment beam is above the protection standard for only laser energy settings of greater than 200 mW. However, the alignment beam irradiance does exceed the long-term viewing standard. For the alignment beam setting No. 2 and the 200 mW laser setting, the maximum allowable viewing time is 1 minute. When the alignment beam is reflected off the coated gonial lens, the viewing time is extended to 2.5 hrs. As this alignment procedure is of short duration compared to the allowable viewing time, and the recommended procedure is to set the alignment beam at No. 1 or No. 2, with adjustment of the laser beam to as low a setting as possible while still maintaining visibility of the alignment laser on the fundus, this should not be a critical factor. Due to the possibility of operating the photocoagulator with time settings greater than 0.25 seconds with radiant powers of 500 mW or greater, this laser is a class IV laser by current Army standards.

b. Federal Performance Standard Requirements. A Federal [Food and Drug Administration (FDA)] standard for laser products (see references 4 and 5, Appendix A) applies to all laser products manufactured after 1 August 1976. The Coherent Model 900 photocoagulator is a class IV laser for FDA standards.

7. CONCLUSION. The Coherent Model 900 photocoagulator emits optical radiation exceeding current protection standards. Direct intrabeam viewing by unprotected personnel should not be permitted within 7 m unless that person is a patient in a treatment status under the direct supervision of an ophthalmologist or other competent medical authority. Eye protection for spectators should provide an attenuation of 24 dB (2.4 O.D.). For normal use when the contact gonial lens is in place on the patient's eye, the reflected-beam NOHD is reduced to 1.6 m (with the coated lens).

#### 8. RECOMMENDATIONS.

a. Insure that the alignment laser is used with as low a setting as possible to extend the allowable viewing time to a maximum while still maintaining good visibility of the alignment beam on the fundus (paragraph 1-4d, AR 40-46).

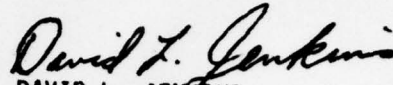
b. Insure that unprotected personnel do not view the laser from within the beam at distances less than 7 m for direct viewing or 1.6 m when viewing the coated gonial lens reflection (paragraph 1-4d, AR 40-46).

c. Provide an adequate SOP which clearly states the hazards from the Coherent Model 900 photocoagulator [paragraph 1-4d and 1-5d(1), AR 40-46].

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d. Insure that unprotected personnel are not allowed access to the area where the photocoagulator is being operated due to possible hazardous reflections from the gonial lens (paragraph 1-4d, AR 40-46).

e. Insure that only anti-reflection coated gonial contact lenses are used for photocoagulation (paragraph 1-4d, AR 40-46)

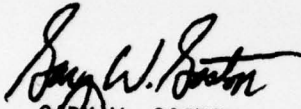


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APPENDIX A

REFERENCES

1. AR 10-5, Department of the Army, Organization and Functions, paragraph 2-35a(7), 1 April 1975.
2. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.
3. TB MED 279, Control of Hazards to Health from Laser Radiation, 30 May 1975.
4. Title 21, Code of Federal Regulations (CFR), 1978 ed., Part 1040, Performance Standards for Light-Emitting Products.
5. DOD Instruction 6050.6, Exemption for Military Laser Products, 1 May 1978.



## APPENDIX B

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS 1, 2

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	$Q_e$		Joule (J)	Quantity of Light	$Q_v$	$Q_v = \int \phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	$W_e$	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter (J·m <sup>-3</sup> )	Luminous Energy Density	$W_v$	$W_v = \frac{dQ_v}{dV}$	talbot per square meter (lm·s·m <sup>-2</sup> )
Radiant Power (Radiant Flux)	$\Phi_e, P$	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	$\Phi_v$	$\Phi_v = 680 \int \frac{dQ_e}{d\lambda} V(\lambda) d\lambda$	lumen (lm)
Radiant Exitance	$M_e$	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cos \theta d\Omega$	Watt per square meter (W·m <sup>-2</sup> )	Luminous Exitance	$M_v$	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cos \theta d\Omega$	lumen per square meter (lm·m <sup>-2</sup> )
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	$E_e$	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter (W·m <sup>-2</sup> )	Illuminance (luminous flux density)	$E_v$	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter (lm·m <sup>-2</sup> ) lux (lx)
Radiant Intensity	$I_e$	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian (W·sr <sup>-1</sup> )	Luminous Intensity (candlepower)	$I_v$	$I_v = \frac{d\Phi_v}{d\Omega}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	$L_e$	$L_e = \frac{d^2\Phi_e}{d\Omega dA \cos \theta}$	Watt per steradian and per square meter (W·sr <sup>-1</sup> ·m <sup>-2</sup> )	Luminance	$L_v$	$L_v = \frac{d^2\Phi_v}{d\Omega dA \cos \theta}$	candela per square meter (cd·m <sup>-2</sup> )
Radiant Exposure (Dose in Photobiology)	$H_e$	$H_e = \frac{dQ_e}{dA}$	Joule per square meter (J·m <sup>-2</sup> )	Light Exposure	$H_v$	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	$\eta$	$\eta = \frac{\Phi_v}{\Phi_e}$	lumen per watt (lm·W <sup>-1</sup> )
				Luminous Efficacy (of a broad band radiation)	$V(\cdot)$	$V(\cdot) = \frac{\eta}{\eta_0} = \frac{\eta}{680}$	unitless
Radiant Efficiency <sup>3</sup> (of a source)	$\eta_e$	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy <sup>3</sup> (of a source)	$\eta_v$	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt (lm·W <sup>-1</sup> )
Optical Density <sup>4</sup>	$D_e$	$D_e = -\log_{10} T_e$	unitless	Optical Density <sup>5</sup>	$D_v$	$D_v = -\log_{10} T_v$	unitless
				Retinal Illuminance in Troilands	$E_t$	$E_t = \frac{L_v}{S_D}$	troiland (td) = luminance in cd·m <sup>-2</sup> times pupil area in mm <sup>2</sup>

- The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word spectral, and the unit is then per wavelength interval and the symbol has a subscript  $\lambda$ . For example spectral irradiance  $H_{\lambda}$  has units of W·m<sup>-2</sup>·nm<sup>-1</sup> or more often, W·cm<sup>-2</sup>·nm<sup>-1</sup>.
- While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or  $\mu$ m are most commonly used to express wavelength.

- $P_i$  is electrical input power in watts.
- $\tau$  is the transmission
- At the source  $I = \frac{d\Phi}{dA \cos \theta}$  and at a receptor  $I = \frac{dE}{dA \cos \theta}$



APPENDIX C

LASER HAZARD CLASSIFICATION GUIDE

The general hazard evaluation techniques used in this survey are discussed in Appendix C of TB MED 279, 30 May 1975. The output parameters from a particular laser determine the potential health hazards and general control procedures during its usage. Experience developed by this Agency from past laser surveys lead to a general classification scheme. Each laser is classified into one of five groups, Class I thru Class V, depending upon its output parameters. The following paragraphs explain the classification system for common laser systems.

1. CLASS I. Exempt (EX) lasers or laser systems are those laser devices which cannot under any condition emit hazardous levels of optical radiation, even if the laser radiation is viewed through collecting optics.

2. CLASS II. Low-power (LP) lasers are those continuous wave (CW) lasers which emit visible radiation and have a total radiant power in excess of 0.4  $\mu$ W but less than 1 mW. Precautions are required only to prevent continuous staring into the direct beam; momentary (<0.25 s) exposure as would occur in an unintentional viewing situation is not considered hazardous.

3. CLASS III. Medium-power (MP) laser systems are divided as follows:

a. Class IIIA. Laser systems with output irradiances less than 2.5  $\text{mW}\cdot\text{cm}^{-2}$  averaged over a 7-mm aperture and whose radiant power lies between 1 mW and 5 mW are Class IIIA medium-power lasers. These laser devices are not hazardous for exposure durations <0.25 s, but require a caution label which instructs personnel not to view the direct beam through magnifying optics.

b. Class IIIB.

(1) A laser system is a Class IIIB medium-power laser if one of the following conditions apply for the laser wavelength:

(a) Infrared (1.4  $\mu$ m to 1 mm) and ultraviolet (200 nm to 400 nm) laser devices which can emit a radiant power in excess of the exempt laser output power ( $P_{\text{exempt}}$ ) for the maximum possible duration inherent to the design of the laser device but cannot emit an average radiant power of 0.5 W or greater for the limiting exposure duration ( $T_{\text{max}}$ ) greater than 0.25 s, or a radiant exposure of 10  $\text{J}\cdot\text{cm}^{-2}$  within an exposure time of 0.25 s or less.

(b) Visible (400 nm to 700 nm) CW or repetitively-pulsed laser devices which produce a radiant power in excess of  $P_{\text{exempt}}$  for a 0.25 s exposure (1 mW for a CW laser), but cannot emit an average radiant power of 0.5 W or greater for  $T_{\text{max}}$  greater than 0.25 s.

(c) Visible and near-infrared (400 nm to 1400 nm) pulsed laser devices which can emit a radiant energy in excess of the exempt laser output energy ( $Q_{\text{exempt}}$ ) but which cannot emit a radiant exposure that exceeds that required to produce a hazardous diffuse reflection as given in Table D-1 of Appendix D, TB MED 279.

(d) Near-infrared (700 nm to 1400 nm) CW laser devices or repetitively-pulsed laser devices which can emit power in excess of  $P_{\text{exempt}}$  for the maximum duration inherent in the design of the laser devices but cannot emit an average power of 0.5 W or greater for periods in excess of 0.25 s.

(2) These lasers are potentially hazardous if the direct beam is viewed by the unprotected eye. Care is required to prevent direct beam viewing and control specular reflections.

4. CLASS IV. Laser systems are Class IV high power (HP) if one of the following conditions apply for the laser wavelength:

a. Ultraviolet (200 nm to 400 nm) and infrared (1.4  $\mu\text{m}$  to 1 mm) laser devices which emit an average power of 0.5 W or greater for periods greater than 0.25 s, or a radiant exposure of  $10 \text{ J}\cdot\text{cm}^{-2}$  within an exposure duration of 0.25 s or less.

b. Visible (400 nm to 700 nm) and near-infrared (700 nm to 1400 nm) laser devices which emit an average power of 0.5 W or greater for periods greater than 0.25 s, or a radiant exposure per pulse in excess of that required to produce a hazardous diffuse reflection as given in Table D-1 of Appendix D, TB MED 279. These pulsed visible and near infrared lasers are hazardous to personnel from direct-beam viewing and from specular and diffuse reflections of the laser beam. Safety precautions consist of using door interlocks, beam stops to terminate the primary and secondary beams and the use of laser safety eyewear.

5. CLASS V. Enclosed laser devices (E) consist of any Class II, IIIA, IIIB or IV laser devices which, by virtue of appropriate design or engineering controls, cannot directly irradiate the eye with levels which are in excess of  $P_{\text{exempt}}$  or  $Q_{\text{exempt}}$ .